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LESSONS FROM THE FIRE IN THE ARGONAUT MINE

BY

B. O. PICKARD

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LESSONS FROM THE FIRE IN THE ARGONAUT MINE

By B. O. Pickard

INTRODUCTION

A fire, which was discovered at midnight, Sunday, August 27, 1922, in the main shaft of the Argonaut mine, caused the death of 47 miners. Rescue workers recovered 46 of the bodies; the forty-seventh was found a year later under fallen rock. Bureau of Mines engineers made a thorough study of the fire and prepared a report for the bureau's study of mine disasters, from which the present paper has been compiled.

ACKNOWLEDGMENTS

Of the many who assisted through collecting and assembling data, and who offered valuable suggestions in the preparation of this manuscript, special mention is due the following: G. S. Rice, Daniel Harrington, H. M. Wolflin, F. C. Gregory, C. H. Fry, Dr. L. H. Duschak, and the officials of the Argonaut Mining Co. Grateful acknowledgment of their assistance is hereby made.

DATA ON THE ARGONAUT MINE BEFORE THE FIRE

The Argonaut mine, which is owned by the Argonaut Mining Co., of San Francisco, Calif., is at Jackson, Amador County, Calif., about 1 mile south of Martel, the terminus of the Amador Central Railroad. (See Pl. I, *A*.) The mining district is called the Mother Lode. The Argonaut is a gold quartz mine and employed at the time of the disaster approximately 165 miners underground and 45 men on the surface. During the year before the castastrophe it treated about 100,000 tons of ore in a 60-stamp mill. The mine is worked through an inclined shaft, called the Argonaut shaft, which follows approximately the dip of the vein to a depth of 4,900 feet measured along the incline. The slope of the shaft is fairly constant, being about 57°. The elevation of the shaft collar is approximately 1,500 feet above sea level. The shaft has three compartments, each 4 by 5 feet in the clear. The nature of the ground in which the shaft was driven required very heavy timbering of the shaft and the stations. Two compartments of the shaft are used for hoisting by skips. The manway, on the north end of the shaft, contains a continuous ladderway, a 3-inch compressed-air line, a 4-inch compressed-air line, a 5-inch pump column, high-tension cable, electric-light wires, and signal and telephone wires. Levels are driven at approximately 150-foot intervals.

A second shaft, called the Muldoon shaft (Pl. I, *B*), is used entirely for ventilation. This shaft proper extends 800 feet below the surface where a horizontal offset connects with a raise from the Argonaut 2,400 level. At the 2,400-foot horizon a second horizontal offset connects with raises from the 3,700 level. From the 3,700 level to the lower levels connections are made through horizontal offsets and connecting raises. The Muldoon shaft and the connecting raises were generally spoken of collectively as the "ventilation raises." This ventilation-raise system was equipped with ladderways from the bottom level to the surface, and was considered to comply with the State law which requires a mine to have a second exit.

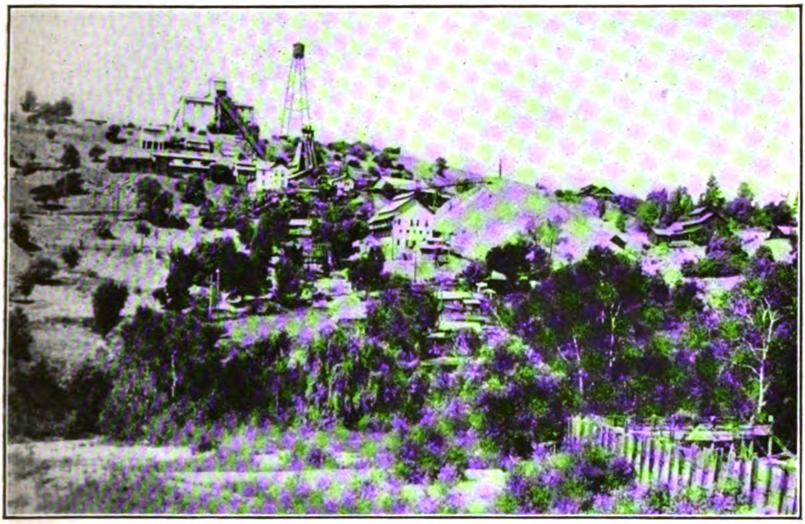
The mine had been extensively developed to the 4,900 level. At the time of the fire stoping was confined to the 4,500 level and those below. The shaft and stations of the mine were electrically lighted.

POWER CIRCUIT

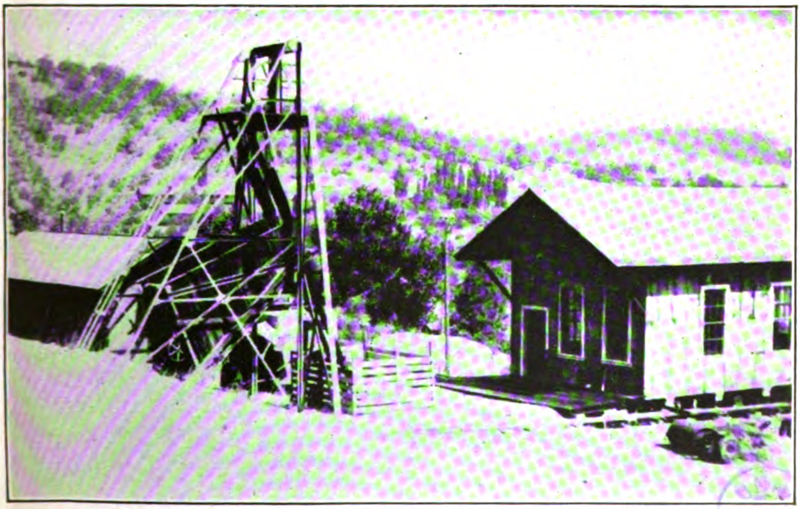
The power cable was made up of three smaller cables of 18 copper wires (No. 14 gauge), each insulated with rubber and cotton fabric. The cable was incased in lead tubing 1¼ inches in diameter, which was in turn insulated with paper, wrapped by hemp cord, armored with heavy galvanized wire wound spirally, and the whole protected from moisture by a covering of tarred hemp cord. The cable was fastened to end plates on spreaders of the shaft on the north and manway compartment by iron clamps 15 inches from the footwall. The cable carried alternating current of 2,300 volts, which came from a transformer passed through a knife switch and through a Westinghouse oil safety switch on the circuit breaker to connections with mine machinery.

Leads from the main cable to pump motors on the 2,000, 3,900, and 4,800 levels, and to a blower on the 4,200 level, were the only side outlet connections. These connections were made through metal junction boxes. Knife switches on the pump station controlled the current to the motors.

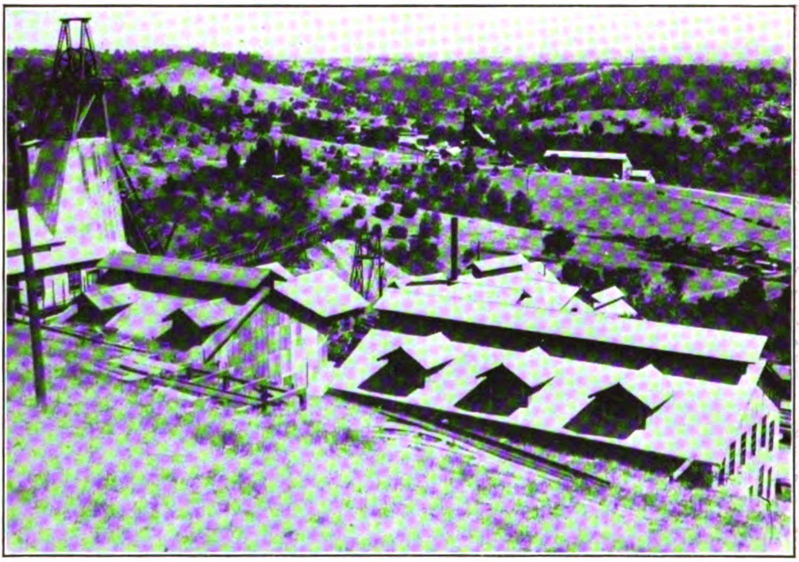
Junctions of the main cable were on the 1,000, 2,000, 3,000, 3,100, 3,900, 4,200, and 4,600 levels. Two types of junctions were in use,



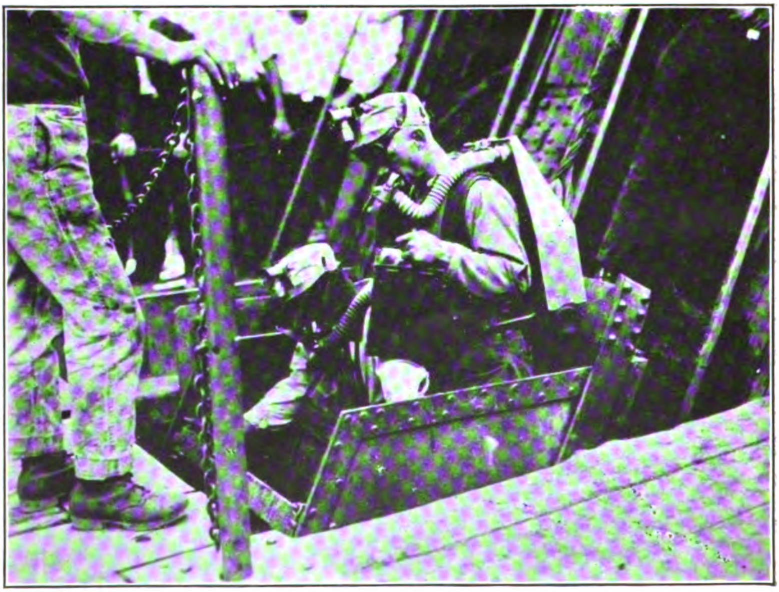
A. PANORAMA OF THE ARGONAUT SURFACE



B. COLLAR AND HEADFRAME OF THE MULDOON SHAFT



A. PANORAMA OF THE ARGONAUT SHAFT ON THE LEFT AND THE KENNEDY SHAFT IN THE CENTER BACKGROUND



B. APPARATUS CREW BEING LOWERED IN THE ARGONAUT SHAFT

A. KENNEDY 3,600 LEVEL

B. APPARATUS MEN ASSEMBLING AT THE KENNEDY COLLAR the metal-box type, containing a knife switch, which allowed the current to be cut when a door was opened, and the "fish" type. Both types had holes to fasten them to timbers with lag screws.

A circuit breaker in the hoisting house was connected to the power circuit, and the company officials stated that the circuit breaker was set so closely that to try to start a pump with only a little water in the column would throw it out.

The pumps used in the shaft had a capacity of 130 gallons a minute, and a 2,000-foot head.

HOISTING

Hoisting was done by two 4-ton ore skips, arranged so that hoisting could be done in or out of balance. "Go-devils," or man cages, were swung underneath the skip when timber or men were being transported in the shaft. Men were lowered or raised in the large go-devils and in unbonneted ore skips, in which short ladders were placed for convenience. Approximately 26 men were carried in one skip and a go-devil underneath.

VENTILATION

The mine was ventilated by an exhaust fan placed at the collar of the Muldoon shaft. The fan was a No. 8 Sirocco, belt-connected to a 440-volt, 50-horsepower motor, with a speed of 800 revolutions per minute. The normal water gauge was approximately 2 inches. The fan delivered approximately 40,000 cubic feet a minute, when running normally at that gauge. No provision was made for the reversal of the air current. The main Argonaut shaft furnished the intake for the air current, and consequently was downcast.

To circuit the air to the working levels below the 4,500 level, doors have been placed between the main shaft and the Muldoon shaft. On each of several levels the doors were in sets of two, one door near the Argonaut shaft and the second near the connection to the ventilation raise. These doors were made of wood, with wooden frames, and were held closed by the air pressure caused by the fan. There was no door below the 4,500-foot level. Although considerable leakage occurred through the doors, limited amounts of fresh air reached the lower workings.

The temperature in the lower workings is high, and without circulation of air by the fan the working places are very uncomfortable. Under normal conditions the air passed down the Argonaut shaft and was delivered directly to the 4,500 and lower levels. From the bottom level the air passed through the return air raises to the Muldoon shaft where it was exhausted by the fan at the collar of the shaft.

LOCAL RESCUE FACILITIES

The Argonaut Mining Co. is a member of the Amador County Cooperative Mine Rescue Station, which maintained six sets of self-contained oxygen breathing apparatus. This station was in charge of R. J. Duncan.

PREVIOUS FIRES

In 1919 and in 1920 the Argonaut had serious fires in its workings. A large mine operated by the Kennedy Mining & Milling Co. joins the Argonaut mine workings on the east. (Pl. II, *A*, p. 3.) The stopes of this mine extend to the boundary line of the Argonaut in many places. There was not a boundary pillar left between the mines, but so far as was known there were no open connections between the mines. Before the 1919 fire several places along the boundary line had been open, but later they were filled with waste and old timber. However, there was said to be leakage of air from the Kennedy mine caused by the suction of the Argonaut fan.

ACCOUNT OF THE DISASTER

MEN UNDERGROUND

At the Argonaut mine, under normal operations, the main work was done in two shifts, from 7.30 a. m. to 3.30 p. m., and from 5.30 p. m. to 1.30 a. m. The hoisting engineer, topman, and skip tender worked in three shifts, beginning at 6.30 a. m. On August 27, 1922, the Sunday night mine shift, composed of 43 men, was lowered in the mine at 5.30 p. m. These men were distributed on the three working levels, namely, 4,500, 4,600, and 4,800, most of them being assigned to work in the stopes on or extending up from the 4,600 and 4,800 levels. At 6 p. m. the shift boss, Clarence Bradshaw, was lowered into the mine. Later five additional men were lowered into the mine to the 4,800 level. At 10.40 p. m. a skip tender was lowered into the mine with lunch buckets and water kegs for the miners. This made a total of 50 men in the lower levels of the mine, consisting of 47 miners, a shift boss, and 2 skip tenders.

DISCOVERY OF THE FIRE

After the lunch hour at 11 o'clock, when the two skip tenders and the shift boss had difficulty in opening the waste chute in the 4,200 level and returned to the 4,200 station, they smelled smoke. They immediately realized that a fire was in the shaft above them, because the smoke was carried down by the intaking current. The three men had themselves hoisted in the shaft until they found the fire just below the 3,000-foot station, where they stopped the skip. In their testimony at the coroner's inquest they claimed that two sets (10 feet) below the 3,000-foot level a fire in the hanging wall was burning in two sets.

After the fire was discovered two of the men were hoisted to the upper levels, and one remained at the 3,000 station to observe conditions. The shift boss, who was one of the two hoisted, stopped at the 2,000 level, and telephoned to the hoisting engineer. During this conversation a miner telephoned from one of the lower levels that smoke was present there. The shift boss told him that the shaft was on fire and that everything possible was being done to extinguish it.

The telephone message was the last communication with the 47 men in the lower workings. All three men who passed through the fire zone testified that the smoke was intense; also that, other than the burning hanging-wall timbers, the shaft was in good condition, that is, the rails, ladderway, signals, and light system were all in working order. After the shift boss had telephoned to the surface, he and one skip tender were hoisted to the collar of the shaft, where conferences were held with the mine foreman and others, and arrangements were immediately made to extinguish the fire by such means as were available.

ATTEMPTS TO CONTROL THE FIRE

Almost simultaneously with the arrival of the shift boss at the surface, the telephone, signal system, and lights in the mine went out of order, and there was no further communication with the lower workings. All attempts made by the foreman and his crew to extinguish the fire were futile, and it was soon realized that the 47 miners left in the mine were in danger of death. They had very little chance to escape through the smoke and gas that was soon pouring out through the second exit, where the suction fan was located. The management then requested all available help, including that from the Bureau of Mines Berkeley safety station.

Conditions in the main Argonaut shaft gradually grew worse, the smoke backing up against the diminished air current until it was unsafe for miners without breathing apparatus to work in the shaft. Explorations were made by men equipped with rescue apparatus and lowered into the shaft by the skip. They soon saw that the fire was spreading so rapidly that it could not be controlled in time to permit skips to pass through the fire zone and reach the lower levels. Meanwhile, as stated before, the smoke was issuing in large quantities from the Muldoon shaft, where the exhaust fan was pulling it out of the mine.

PROPOSED REVERSAL OF THE FAN

Many discussions were held as to the advisability of reversing the fan. However, as stated before, the fan had no reversible equipment, and changes in the fan casing to permit reversal of the air current could not be made inside of four or five hours. The management believed that the reversing of the air current would in no way affect the fire, as the air would be short-circuited through the doors in levels above the fire zone, because the doors on those levels would be swung open by the reversed air pressure. The mine manager said that it was barely possible that a supply of fresh air was coming from the Kennedy workings in the vicinity of the Argonaut 4,200 station, where there had always been a leakage of fresh air, and if the entombed miners succeeded in reaching these fresh-air currents the reversal of the fan would force the foul gases in on them. The air current was not reversed during all the fire fighting.

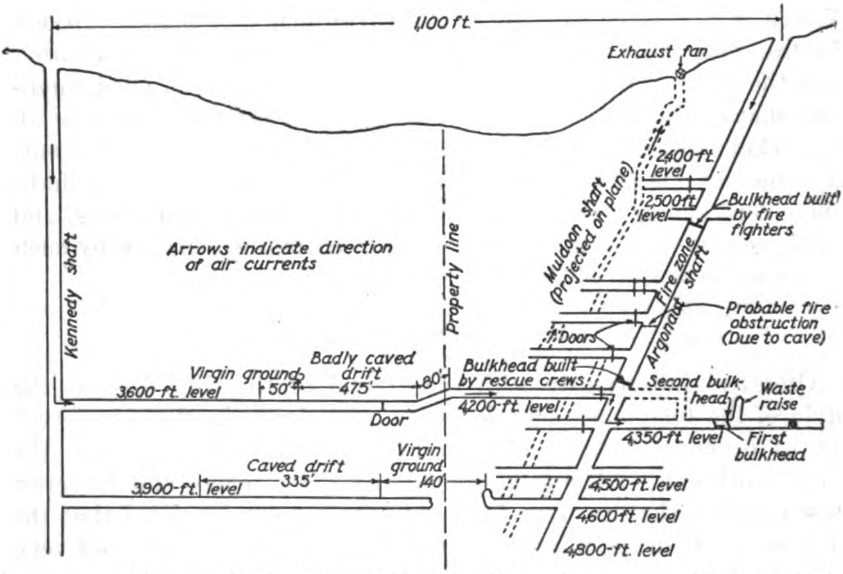


FIGURE 1.—Diagram of the Argonaut-Kennedy fire and rescue workings and the adjoining Kennedy mine. Distances are approximate

PROPOSED EXPLORATIONS

There was considerable discussion as to whether or not men in apparatus could go down the Muldoon shaft. A study of the conditions in that shaft and in ventilation raises below it revealed the impossibility of apparatus men reaching the lower workings through the ventilation raises. The return air was carrying smoke and poisonous gases from the fire; to reach and return from the lower levels of the mine, the men would have to go down a mile of raises and drifts, and then climb back—all within two hours—to keep within the working limits of the breathing apparatus. As was pointed out, the oxygen and chemicals of the breathing apparatus would be consumed before the trip was completed. It was believed that a man in good condition, breathing good air and without the weight of apparatus, would require four or five hours to climb out of the mine.

Bratticing the Muldoon shaft, in order to make an intake compartment, was considered, but this project was abandoned as impracticable on account of the long distance and the necessary climbing.

The installation of a hoist and hoisting equipment in the Muldoon shaft and the connecting ventilation raises was considered and abandoned as impracticable.

In desperation, as there seemed no other way, an attempt to go through the Argonaut fire zone was planned. A call was immediately put in for all the oxygen breathing apparatus men in California, and from some mines in Nevada. Plate II, *B* (p. 3), shows apparatus men being lowered in the shaft.

EXECUTIVE AND ADVISORY COMMITTEES

All fire-fighting operations were placed in charge of an executive committee composed of S. Garbarini, manager of the Argonaut Mining Co., chairman; E. C. Hutchinson, president of the Kennedy Mining & Milling Co.; and Fred L. Lowell, mining engineer of the Industrial Accident Commission. This committee was assisted by an advisory committee consisting of all of the State, Federal, and local mine executives who had assembled at the mine and had offered assistance.

BULKHEADING OFF FRESH AIR

The breathing-apparatus men eventually controlled the extension of the fire up the shaft by means of a high-pressure water line and hose (fig. 2); they then placed a bulkhead in the shaft to cut off the air supply to the fire zone. This bulkhead was 11 sets below the 2,550 station and 5 feet above the upper limit of the fire zone. (See fig. 1, p. 6.)

After the bulkhead was complete, a regular patrol was established and samples were taken of the gases below and above the bulkhead, and in the 2,400 south drift connecting the Argonaut and the Muldoon shafts. The air pressures were noted at the bulkhead and at the 2,400 south drift doors. It had formerly been agreed that an intelligent sampling and analysis of the return air would be of great value in determining the condition of the fire area. Dr. L. H. Duschak,

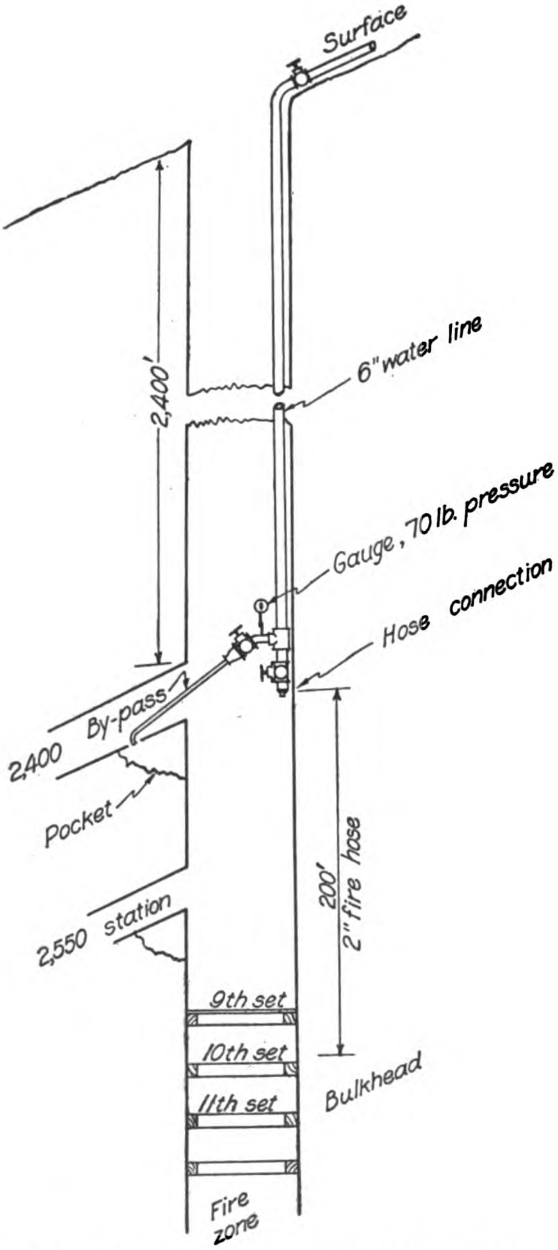


FIGURE 2.—Water line and hose connections used in extinguishing the fire below the 2,250-foot station, Argonaut mine

consulting chemical engineer for the Industrial Accident Commission, was placed in charge of this work.

DRIVING THROUGH FROM THE KENNEDY MINE

When the executive committee realized that access to the Argonaut lower workings through the Argonaut and Muldoon shafts was impossible it accepted the proposition of President Hutchinson, of the Kennedy Mining & Milling Co., to reach the lower workings of the Argonaut mine through the Kennedy lower levels. On August 29 work in driving the Kennedy 3,600 level, which would eventually connect with the Argonaut 4,200 level, was started and prosecuted with diligence. (See fig. 1, p. 6.)

Other operations in the Kennedy mine were stopped and entire attention was given by the Kennedy officials to the driving and opening up of the 3,600 level. Volunteer crews from both the Kennedy and Argonaut and other near-by mines were put to work on six-hour shifts. The engineers determined that the shortest possible distance from the Kennedy 3,600 to a connection with a crosscut from the Argonaut 4,200 station would be 1,400 to 1,500 feet long, and would necessitate cleaning out old workings that were known to be tightly caved in some places and partly caved in others. They also determined that they must drive a crosscut in virgin ground for 50 feet and a raise in virgin ground which would be at least 80 feet incline distance. The exact conditions of the ground ahead were not known, but the attempt was made in the hope of arriving in time to find the entombed miners alive.

On August 30 the executive committee decided that as an emergency operation, on account of the uncertain conditions which might be encountered in the 3,600, that the 3,900 south drift of the Kennedy be also driven, in order to connect with the Argonaut 4,600 stopes. This entailed driving a crosscut through 140 feet of virgin ground.

Never was harder or more trying work done by miners. Not only was the air poor, the heat intense, the air saturated, the backs of the drifts low, but there was not time even to put in tracks to wheel out the rock, so that wheelbarrows were used and all open places filled up in order to dispose of the rock removed. To the credit of the volunteer miners who did this work it should be recorded that they never lost heart nor faltered in the work, and when one man was tired out a fresh man took his place.

Instead of only a week, as was hoped, 21 days of the hardest kind of work were needed to break through from the last raise in the 3,600 to the Argonaut 4,200. The conditions encountered were much worse than were feared, when the project was proposed.

The earnestness and intelligence with which these men applied themselves to the work and the intelligence with which they were directed are shown by the fact that 80 feet of raise in virgin hard rock was driven in 36 hours, and a 50-foot crosscut in virgin hard rock was driven in 24 hours. Opening up the caved workings took much time. Plate III, *A* (p. 2), is a view of the Kennedy 3,600 level.

The 3,900 level required timbering as fast as it was opened, and here also records were made, and the miners were within a few feet of breaking through when it was announced that the 3,600 level had beaten them by a few hours. Work was immediately abandoned on the 3,900.

EXPLORATION AND RECOVERY WORK

On Monday morning, September 18, the twenty-second day of the disaster, the raise driven to connect the 3,600 Kennedy with the 4,200 Argonaut level broke through. When the opening was large enough for apparatus crews to pass, the miners were withdrawn and the apparatus men were lowered into the Kennedy mine (Pl. III, *B*), whence they proceeded through the connections to explore the lower workings of the Argonaut mine according to the prearranged plan.

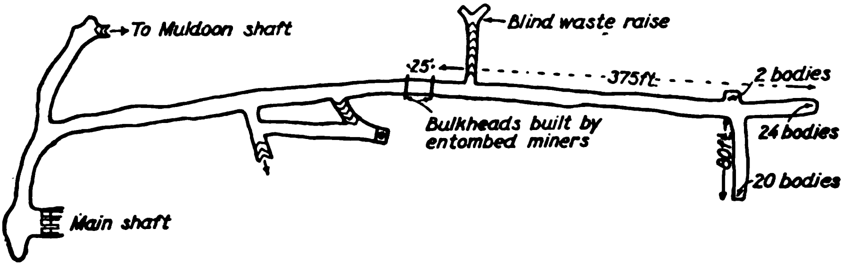


FIGURE 3.—Plan of the Argonaut 4,350-foot level

At 4.28 that afternoon on the 4,350 level the explorers discovered a bulkhead built by the entombed miners. The air in front of the bulkhead was so poisonous that a canary bird dropped from its perch and carbide lights were extinguished. The party broke down this bulkhead and 25 feet inside discovered a second bulkhead built like the first. They broke down this second bulkhead, explored the crosscut, and discovered 46 bodies in the far end of the workings where the entombed men had all retreated. Some were sitting holding their heads in their hands, others were lying with their coats under their heads, others had fallen forward on their faces, and two or three piles of bodies were found. The bodies were badly decomposed and covered with mildew.

Removal of the bodies from the mine was the next problem. A tugger hoist was installed on the 4,200 station, and a wooden box, or improvised skip, was attached to a cable. This box had wooden skids, which, when greased to overcome friction, enabled it to slide on the skip rails in the shaft.

After partly restored ventilation had carried away the poisonous gas, the men working in shifts and wearing apparatus (about a half dozen men braved the stench without apparatus) rolled the bodies in canvas, placed them on Stokes-Navy stretchers, and carried them to the 4,350 station. From this station the bodies were hoisted in the stretchers and delivered by fresh-air men, working in relays, to the surface.

When the bodies were discovered the air in the crosscut was noxious, as already stated. A compressed-air line, connected to the air supply from the Kennedy 4,200 level, was brought into the crosscut to supply fresh air, but did not supply enough to overcome the foul conditions.

At 9.41 p. m., September 20, the last of the 46 bodies was delivered to the surface. As one man of the 47 had not been accounted for, thorough search of the mine for his body was made by apparatus men the following day, but without success. Extended search in the mine had to be abandoned pending unwatering of the lower levels, which at this time were filled with water practically to the 4,500 station. The forty-seventh body was found on a lower level after the mine was unwatered.

EFFORTS OF ENTRAPPED MEN

Action of the entombed men after they had been warned by telephone of fire in the shaft is hard to determine, but one can readily imagine that after the smoke was discovered the carmen and other men on the level notified the miners working in the stopes, and all of them made strenuous efforts to get out by the second exit. They probably found the smoke too dense to climb great distances. Some one took charge and led them to the 4,350 level, through the ventilation raises, and into the long crosscut from this level. On their way there they collected much material for bulkheads. Who their leader was is also a matter of conjecture. Presumably they were led by Fessel or by Miller, who were both supposed to be very level-headed and more than ordinarily intelligent.

CONSTRUCTION OF BULKHEADS

The men on reaching the 4,350 level started to build a bulkhead. Many of their dinner buckets were found on the 4,500 level, indicating that they probably assembled at this point and considered plans for escaping from the mine or protecting themselves from the gases. They left open the 4,500 ventilation door, which was the only door in the mine that the miners had touched. Why they did not open the door on the 4,350 level and short-circuit the gases is not understood. One conjecture is that they considered the short circuit at 4,500 enough and that the door on the 4,350 would give a certain amount of protection. Also, presumably, they thought the fire would be put out quickly and they would be rescued in a short time. It is questioned why one of them did not attempt to go to the upper levels and open doors above their place of refuge, in order to short-circuit as much of the gas as possible. The smoke was probably too strong. Evidently before they completed their first bulkhead enough gas had leaked through to cause distress, for otherwise they would not have taken the time and energy to build a second bulkhead. The second bulkhead was poorly built—a sign of haste and weakness. A large hole was left in one of the upper corners.

Between the place selected for the bulkheads and the face of the long crosscut a raise was being driven to develop ore above the level. Considerable work had been done in the raise, and the last round broken had been left in the chute. The entombed miners took advantage of this waste rock in building their bulkhead. First of all, they put in a 2 by 4 board across in the back, and securely wedged it. They then placed such spiling, chute boards, 2 by 12 boards and other miscellaneous timbers as they had been able to collect against the 2 by 4 board with the ends resting on the floor of the crosscut. They used an empty powder box, which had been found in the crosscut, to carry waste rock from the chute mentioned. This broken rock was thrown against the bottom of the bulkhead. They attempted to fill all of the holes with their jumpers, shirts, and underclothing.

Construction of the second bulkhead differed from the first in that more rock and less clothes were used. Figures 4 and 5 show the details of the construction and the location. After the miners finished the second bulkhead they retreated to the far ends of the crosscut.

MESSAGES LEFT BY THE MEN

One man in the extreme end of the crosscut attempted to keep a record by writing with the smoke of the flame of his carbide light on the slate face of the crosscut. (Fig. 6.) He succeeded in writing "3 o'clock gas getting strong" and signing the name "Fessel." He later wrote the figures "3.20," "4 o/cl." The carbide light with which this writing was done was found immediately below the unfinished "cl" in 4 o'clock. Presumably he was overcome about this time by carbon monoxide. Some other miner, in a dissimilar handwriting, had written on the face with a piece of slate the words "3.40 (?) ½ knocke out." These were the only messages found

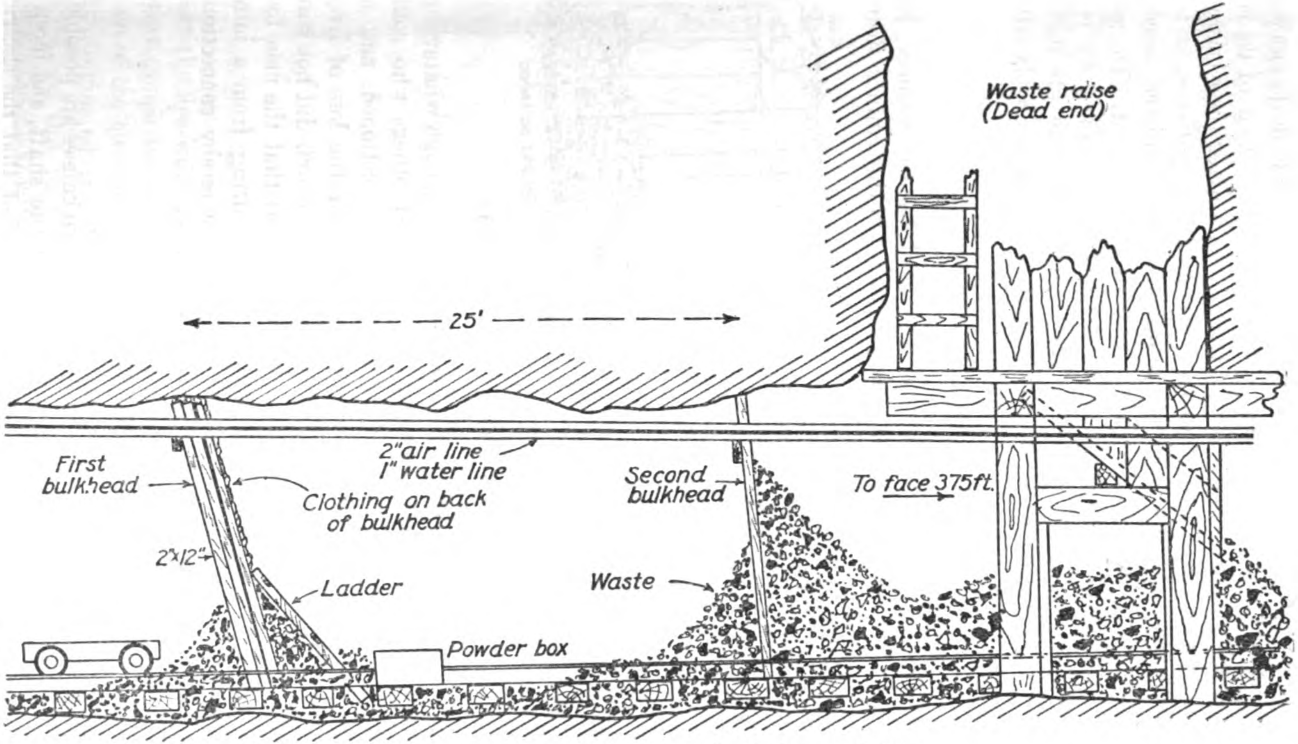


FIGURE 4.—Details of barricades in the Argonaut mine.

that had been made by the entombed men, though their clothes, tobacco cans, lamps, and other equipment were carefully searched.

From these messages and from the condition in which the men were found they evidently had died early on the morning of the fire, probably between 4 and 5 o'clock; that is, soon after their bulkhead was completed. No indications of struggles, impatience, or fear were observed. At the time the bulkhead was completed considerable toxic gas is believed to have been in the crosscut. The testimony of undertakers and others at the coroner's inquest was positive that the men died within a few hours after the fire started, and that their deaths were caused by suffocation, or probably carbon monoxide.

CORONER'S INQUEST

An unusually thorough inquest was held by the coroner, Mrs. Dolores Potter, in which she was assisted by the county district attorney. Practically everyone who had any knowledge whatever of the conditions before and during the fire, and others who could qualify as expert witnesses, were thoroughly questioned, and an attempt was made to place the responsibility for the loss of lives. However, the coroner's jury rendered a verdict which did not state the cause of the fire or place the blame, but said that the men lost their lives through suffocation from gases resulting from a mine fire, and recommended that a law be passed whereby connections between neighboring mines should be maintained.

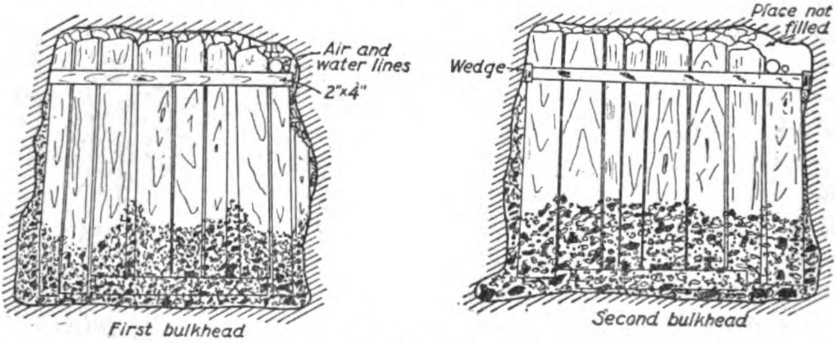


FIGURE 5.—Front view of barricades

CAUSES OF THE FIRE

The definite cause of the fire is unknown. Two causes are possible, a short circuit in the 2,300-volt power line in the shaft, and incendiarism. Public investigators strongly contended that the electric origin is the more probable; the officials of the Argonaut mine strongly maintained that the origin was incendiary.

The governor's investigating committee confined its investigation to interviewing witnesses. This committee stated that it believed the fire started in the manway; that it was unable to arrive at a definite opinion as to the origin, but believed this to be incendiarism or else defective wiring.

THE CASE FOR ELECTRIC ORIGIN

The skip tender who was left at the 3,000 station for several minutes and saw the fire burning testified before the coroner's jury that the fire was burning more freely in the manway than in any other compartment, and that it was spreading from about the location of the electric wires in the shaft. As has been mentioned, the fire originated immediately below the ore pocket from the 3,000 level. At this particular place there was a junction box, through which the 2,300-volt cable passed. The splices in the high-voltage cable at this point were made by means of cast-iron junction boxes of the so-called fish type. This particular junction box consisted of a cast-iron cylinder 6 inches in diameter and 15 inches long, with

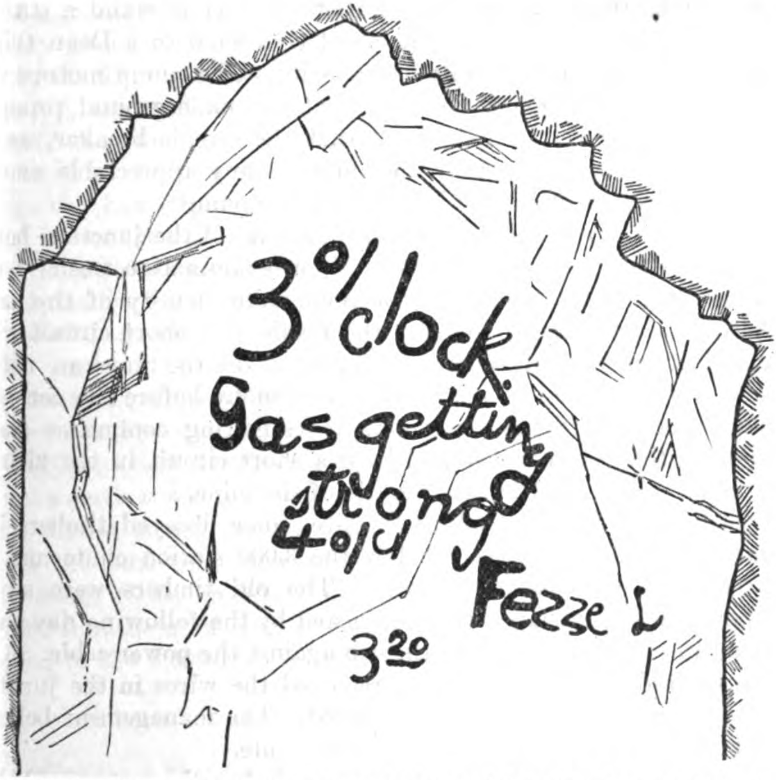


FIGURE 6.—Message left on the face of the barricaded crosscut by entombed men

hemispherical ends, through which a 1½-inch hole allowed the cable to enter. It was cast in two parts, which had machined faces, permitting close contact between the two parts. Lugs at each corner, with holes for ⅝-inch bolts, held the two halves in place after the connection had been made. The three smaller cables, composing the main cable, were separated with an insulating compound. The armor and outer insulation had to be removed from the cable to allow it to enter the ends of the junction box.

At the time the fire was discovered the current pressure was on in the underground 2,300-volt circuit, but no pumps were running. The circuit breaker in the engine room was set to stand a starting load of a 75-horsepower motor, direct connected to a Dean triplex pump of 150 gallons per minute capacity. The pump motors were started by throwing a knife switch at the underground pumping stations. The electrician testified that the circuit breaker, as set, would throw out, in starting the pump, if any appreciable amount of water was in the water column above the pump.

After the fire zone had been opened, a part of the junction box at the 3,000 station was discovered. Upon examination positive evidence of arcing was found in the immediate vicinity of the cable. Whether or not this arcing was the result of a short circuit when the fire started or at some time previous to the fire can not be stated, but the mine officials in their testimony before the coroner's inquest and before the governor's investigating committee stated positively that there never had been a short circuit in the vicinity of the 3,000-foot level during the life of the mine.

On the day shift preceding the fire, some decayed timbers had been taken out immediately below the 3,000 station chute and replaced by a new set of timbers. The old timbers were stored temporarily in the manway to be hoisted by the following day shift. These timbers may have been thrown against the power cable. Also, when the old set of timbers was removed the wires in the junction box may have been jarred or displaced. The management believes that trash had accumulated in the 3,000 chute.

Another fact brought out was that once before the power cable had been punctured in some manner near the 3,900 level and shorted to the shaft timbers. The circuit breaker at that time was repeatedly thrown out while search was being made for the break. The timber took fire and the break in the power line was discovered through the fire.

The mine electrician stated that before the old timbers at the 3,000 level were replaced he had loosened the insulator on either side of the changed shaft set to permit shifting the wires during retimbering. These insulators were not refastened after the timbers had been replaced.

The combination of all of the evidence above outlined leads to the conclusion that the fire could have been caused through a short circuit either in the junction box or in the high-voltage cable itself, the flame igniting either the trash in the chute or the punky timber stored temporarily in the manway. It is believed that there could have been enough shorting in the line without the circuit breaker being thrown.

THE CASE FOR INCENDIARY ORIGIN

The evidence advanced by the Argonaut mine management for a fire of incendiary origin is as follows: *a*, The fire spread with greater rapidity than would usually be expected in such heavy timbering; *b*, the 1919 fire was clearly proved to have been of incendiary origin; *c*, among the I. W. W. element of the country are individuals who would be capable of such actions, and such persons have on several occasions started mine fires; and *d*, one in authority in the mine had stated that footprints were discovered in a drainage tunnel below the collar of the shaft soon after the fire, but whether these were old or new tracks could not be determined. If anyone started the fire he could have climbed up the manway compartment to the drainage tunnel and escaped without observation.

The arguments against incendiary origin are that it would have been practically impossible for anyone to have climbed from the 3,000 foot level and escaped without being discovered. Also, that if anyone had had a desire to fire the mine he could have found other places near the surface where greater damage to the mine would have been done; that it is not very probable that he would have set the fire during the time that there were fellow workers in the mine; also, there seems to be an absolute check on all of the men who were lowered into the mine, and it is not probable that anyone would have climbed to the 3,000-foot level to start a fire and then climbed out.

ANOTHER POSSIBLE CAUSE

Another cause that has been advanced as to the origin of the fire is that a cigarette or match might have been thrown in the hanging-wall sets as the miners were being lowered.

CRITICISM OF ACTION ON DISCOVERY OF THE FIRE

The shift boss immediately upon smelling smoke tried to find the fire, and after finding it had himself and one companion hoisted above the fire; there he telephoned to the surface and later to one of the entrapped men. (See p. 4.) He has been severely criticized, but it must be remembered that his action is typical of the total unpreparedness of many mines for such an emergency. He could not be blamed for leaving his crew while he was hoisted up the shaft to find the source of the smoke. But he may be justly criticized for not remembering the men in his charge, and for not making some more or less heroic attempt to warn them of their danger and to bring them to a place of safety. He justifies his action by the belief that the fire could be extinguished before the men's lives were endangered.

No attempt was made to lower the skip back through the fire zone to the lower levels, so that the men could be hoisted. Failure to do this was again justified by the fact that those in charge believed the fire could be extinguished before lives were endangered. Although such an attempt might have been futile, since the signal systems were out of order within half an hour after the fire was discovered, it is the opinion of some engineers that less than half an hour would have been required to hoist the men above the fire. On this point chiefly is the conduct of the shift boss open to criticism.

Another precaution which would have given the entombed men a chance was the opening of all the ventilating doors to short-circuit the smoke and gases. This might have enabled the men to bulkhead themselves in fresh air at least, and although it might have only prolonged their agony, it might have enabled some of them to have lived the three weeks.

These suggestions are offered merely for the value they may have as guides in formulating plans to anticipate future disasters. The mine that has anticipated and made definite plans for fire fighting will have materially lessened its catastrophe hazard.

CRITICISM OF CONTROL OF AIR CURRENTS

The most debated subject in connection with the mine fire, and one which has been covered at length by discussion in the technical press, was possible control of ventilation. Those in charge and in attendance at the mine fire, and who were thoroughly familiar with all of the conditions prevailing, did not believe that reversal or stoppage of the fan could be justified. To change the direction of the air currents would have required reversing the intake and outlet of the fan and placing a tight cover over the Muldoon shaft. The fact remains that the fan could not have been reversed within three or four hours, and all of the ventilation engineers admit that three or four hours after the discovery of the fire the lower workings were full of poisonous gases and reversal of the air currents would have been too late.

The immediate stoppage of the fan by the shift boss has also been discussed and favored by certain technical writers, who claim that if the fan that was upcasting air in the Muldoon shaft had been stopped the air in the downcast Argonaut shaft would have been immediately reversed by the fire, and the second exit of the lower workings would have been free from poisonous gases. It must be remembered in connection with this theory, however, that the fire originated at the 3,000 level, where only two sets of timbers were burning; that the smoke had entered the lower workings within a few minutes after discovery of the fire; and that the Argonaut shaft is naturally a downcast shaft and the temperatures between the 3,000-foot level and the collar are much cooler than in the lower levels.

The ventilation doors at the several connecting levels between the Argonaut shaft and the return airway, or emergency exit, were held closed solely through the suction pressure of the exhausting Muldoon fan. Either stopping the fan or reversing it would have caused all of the doors to open and short-circuit the air above the fire area.

In making plans to anticipate similar situations at other mines, the fact should be kept in mind that if the ventilation doors had been properly constructed and the fan arranged for quick reversal the air currents could have been reversed and the emergency exit kept clear of poisonous gases.

WORK OF THE MINERS IN DRIVING THE KENNEDY LEVELS

No report of the Argonaut mine fire would be complete without special recognition of the splendid efforts of the miners who drove the 3,600 and 3,900 Kennedy levels to connect with the Argonaut workings. Their exertions under almost unbearable conditions stand out strongly above every other effort made to rescue the entombed men. For three weeks these miners worked under the direction of their bosses, and it is to the credit of their bosses and the men that no effort was left unexpended to reach their entombed comrades. Miners from the Kennedy and Argonaut mines and from many other mines of the Mother Lode could hardly be prevented from working in the drifts.

In the Kennedy 3,600 level, which eventually broke through, 130 feet of virgin ground was broken and removed, and 720 feet of caved drift opened up and the caved material removed in three weeks. Much of the caved material was not ordinary caved ground, but consisted of mud and old timbers, the mud being an extremely soft wet clay material for almost 3 feet above the floor at the point where they were mucking. In order to walk on top of the material it was necessary to lay planks. If a man stepped off the planks he would sink above his knees in the mud. After every shovelful the shovel had to be cleaned. Most of the ground had to be spiled in order to hold the back. There was no time to put in tracks, so wheelbarrows had to be used, which were worked in relays. The temperature in the 3,600 drifts ranged from 84° to 91½° F. wet bulb. The ventilation was poor, and there was no time to wait for the smoke to clear out after blasting or for ventilation pipes to be brought to the face.

On the 3,900 level the working conditions were better, for most of the work done was in virgin ground, but there also drilling and shoveling records were broken.

RECOVERY AND PROPOSED RESCUE WORK

ORGANIZATION

As soon as it became evident that the Kennedy 3,600 would break through within a few hours, the temporary mine rescue station which had been established at the Argonaut mine was transferred to the Kennedy and the apparatus men were organized for the rescue work in the lower levels of the Argonaut. The executive committee gave the Bureau of Mines entire control of the rescue work after the break through was made. Hospital arrangements had been provided on the surface, and the necessary supplies to carry on all work had been accumulated. Definite arrangements had been provided to care for possible live miners and to dispose of the dead bodies.

In the proposed rescue, recovery, and control program, four branches of the work had been considered and assigned to various chiefs: *a*, The mine rescue apparatus work in gaseous areas; *b*, the care of any live entombed men; *c*, the disposal of all bodies; and *d*, the cooperation of miners who could work in fresh air.

H. M. Wolflin, consulting engineer of the Bureau of Mines and superintendent of safety for the Industrial Accident Commission, was placed in charge of all surface work. C. H. Fry, safety engineer for the Industrial Accident Commission, was made superintendent of fresh-air crews. E. W. Bullard took charge of first-aid, recovery, and other supplies. Orr Woodburn, of the Globe-Miami rescue station, was made underground assistant to the writer, who was made director in charge of all rescue operations. L. H. Duschak supervised the gas-analysis work. C. E. Kindall, Bureau of Mines district surgeon, directed the medical work underground.

MINE RESCUE TEAMS

The mine rescue teams were arranged in three groups, *A*, *B*, and *C*, with two teams of four men and a captain each, called team 1 and team 2, in each group. The fresh-air crews were similarly organized, but with larger numbers in the crew, ranging from 25 to 50, depending upon the work assigned.

A total of 1,600 man-hours were spent by 60 men wearing oxygen breathing apparatus.

The following captains and substitutes, named in the order of their rank, were assigned to the apparatus crews: Hecox, Martinson, Sullivan, Duncan, McDonald, and Harrington; substitutes, Birchard, Riddle, Harry, and Sanguinetti.

The other men not assigned to teams were used as substitutes or for special work.

For apparatus work in exploring the lower Argonaut workings through the Kennedy 3,600-foot level, group *A* entered the gaseous workings first, team 1 exploring in one direction and team 2 in another. Group *B* supported at the fresh-air base and group *C* was in reserve on the surface. When group *A* finished its shift in the gaseous workings, it went to surface for a rest and was replaced by group *B*, while group *C* supported at the fresh-air base.

FIRST-AID TEAMS

The rescue plans arranged by the Bureau of Mines before the Kennedy level broke through considered the possibility of discovering live men and provided for proper first aid to such men. All men available who had been trained in proper first aid to the injured were organized and instructed as to what to do under the circumstances. These men were under the immediate supervision of Dr. C. E. Kindall, chief underground surgeon. As no live men were found, however, the first-aid teams had no call.

Doctor Kindall examined the apparatus men and completed the organization for underground first aid and the recovery of bodies. Through his efforts also all of the Bureau of Mines men were kept in good physical condition. He took extreme interest in the welfare of all of the workers and rendered very valuable services. His report follows:

> Before the actual work of underground exploration was started, the rescue or apparatus men were given physical examinations to determine their fitness to wear the apparatus.
>
> These men were then organized into teams of a captain and four men each. In case the miners were found alive, the first-aid men were instructed to remove them to air free from gas if possible and administer artificial respiration and oxygen. From this point the miners were to be carried to the 3,600 Kennedy station, where they were to be fed small quantities of warm milk and broth at frequent intervals, and stimulated with camphorated oil when necessary. They were to be kept warm and their eyes blindfolded.
>
> The writer accompanied the men to the 4,350 Argonaut station to watch the rescue men and be ready for service in case live men were found. It was finally agreed that he should give the first treatment to those found alive and then send them to the 3,600 Kennedy station, where Doctor Endicott was to take charge with first-aid supplies. Doctor Endicott was to keep

the men there until safe to send to the surface, where local and State physicians were waiting with ambulances to take the survivors to the hospital.

The following supplies were taken underground: 3 dozen ampoules of camphorated oil, 6 ounces of aromatic spirits of ammonia, 2 dozen ampoules of amyl nitrite, 5 dozen sterile compresses and bandages, 6 blankets, 2 stretchers, and 1 pint of alcohol for sterilizing hypodermic needles.

On the surface milk and soup were waiting in case of necessity.

Apparatus men at end of each shift of removing bodies were instructed to wash off with a 1/2 cresol solution before bathing, to eliminate all chances of infection.

COOPERATION OF FRESH-AIR MEN AND APPARATUS WEARERS

The term "fresh-air men" means the miners who worked in conjunction with the apparatus men, following up the apparatus wearers, and doing such work in fresh air as would assist apparatus men in their explorations. The fresh-air men, who were organized under the direction of C. H. Fry, were given to understand that the apparatus men were confining their efforts to work in gas. The fresh-air men cooperated in all underground exploration and in the recovery of the bodies. They brought in the supplies, built bulkheads and doors in fresh air, and carried the dead bodies to the surface after delivery to the 4,200 fresh-air base.

USE OF OXYGEN BREATHING APPARATUS

Much valuable assistance in the control of the fire, the attempted rescue of the miners, and the eventual recovery of the mine and bodies was rendered by the volunteers who wore oxygen breathing apparatus. R. F. Duncan, foreman of the Amador County Cooperative Mine Rescue Station, was the first apparatus man to report to the Argonaut mine, and he immediately arranged to secure the assistance of all available men trained in the wearing of apparatus. About sixty apparatus men, including a team from the United Comstock mine, at Goldfield, Nev., and nine students from the mining college of the University of California volunteered for apparatus work.

In the district including California the Bureau of Mines maintains a safety station at Berkeley, Calif., and also a steel mine rescue car with headquarters at Reno, Nev. The station and car are fully equipped and have a personnel of foreman miners, first-aid miners, mining engineers, and surgeon. The Bureau of Mines, in addition to the California and Nevada apparatus and personnel, sent the rescue car and men from the New Mexico-Colorado district, and D. Harrington, then supervising mining engineer of the bureau.

The station and car crews reported to the mine with full equipment and supplies, and under the direction of the district mining engineer representing the bureau volunteered for such assistance as they were able to render.

Principally through the use of apparatus and the volunteer wearers it was possible to make exploration in the burned areas, to take gas samples and anemometer readings, to control and extinguish the fire in the Argonaut shaft, to explore the Argonaut workings after the Kennedy connection had been made, to restore ventilation, to find and recover the dead miners, and to do other work which would not have been possible for men without apparatus. This work was done without dissension and without injury to a single apparatus wearer.

The apparatus men who volunteered from neighboring mines put themselves under the guidance of the Bureau of Mines representatives who were given charge of this part of the work by the executive committee. One of the outstanding features of the apparatus work was the cooperation of volunteer apparatus wearers and the Bureau of Mines representatives. The Bureau of Mines representatives found every apparatus man willing to cooperate with them in carrying out any proposal made or even suggested.

USE OF AIRPLANES

Airplanes were freely furnished by the United States Army at the Presidio in San Francisco, and were used to great advantage in the rescue operations to expedite transportation of men and supplies from San Francisco to Jackson.

NAMES OF WEARERS OF APPARATUS

Name	Place
Pete Accher	Argonaut mine, Jackson.
Joe Amie	Kennedy mine, Jackson.
W. D. Anthony	Shawmut.
W. M. Balling	U. C. College of Mines, Berkeley.
Frank Bernasconi	Melones.
E. E. Birchard	Bureau of Mines, Denver.
W. E. Blair	United Comstock mines, Gold Hill, Nev.
W. Buckley	Melones.
S. Cade	United Comstock mines, Gold Hill, Nev.
F. Carter	Empire mine, Grass Valley.
C. L. Cooper	Jackson.
H. Cordell	Empire mine, Grass Valley.
H. Crouch	Do.
M. Curtoni	North Star mines, Grass Valley.
George Downing	Argonaut mine, Jackson.
R. J. Duncan	Plymouth mine, Plymouth.
C. M. Dunn	U. C. College of Mines, Berkeley.
R. C. Eisenhaur	Melones.
T. Eveley	Empire mine, Grass Valley.
D. A. Fontanella	Melones.
E. J. Garbarini	Argonaut mine, Jackson.
J. E. Lichtenfeld	Shawmut.
A. G. Lindsay	North Star mines, Grass Valley.
H. F. Lorentzen	Argonaut mine, Jackson.
B. F. McDonald	Bureau of Mines, Berkeley.
A. J. Marden	United Comstock mines, Gold Hill, Nev.
A. J. Martinson	Bureau of Mines, Berkeley.
J. Metz	U. C. College of Mines, Berkeley.
Philip Moore	Empire mine, Grass Valley.
J. W. Ninnes	Plymouth mine, Plymouth.
V. D. Perry	Melones.
Claude Porterfield	United Comstock mines, Gold Hill, Nev.
W. A. Riddle	Fremont mine, Amador City.
E. D. Rooney	U. C. College of Mines, Berkeley.
A. Rossi	Argonaut mine, Jackson.
Ben Sanguinetti	Do.
G. E. Seivert	U. C. College of Mines, Berkeley.
L. E. Seivert	Do.
Bob Serger	Melones.
Harry Sharer	Shawmut.
Frank Stage	Argonaut mine, Jackson.

NAMES OF WEARERS OF APPARATUS—continued

Name	Place	Name	Place
J. M. Harrington	Bureau of Mines, Berkeley.	W. F. Sullivan	Bureau of Mines, Berkeley.
C. Harry	Melones.	J. H. Travers	U. C. College of Mines, Berkeley.
R. B. Hecox	Bureau of Mines, Berkeley.		
H. H. Heistand	Melones.	C. Vores	Jackson.
William Hooper	North Star mines, Grass Valley.	G. W. Wiles	U. C. College of Mines, Berkeley.
T. James	Empire mine, Grass Valley.		
R Jeffrey	Do.	S. E. Woodworth	Jackson.
Arthur Kendall	North Star mines, Grass Valley.	G. C. Worthington	Empire mine, Grass Valley.
D. Kitts	Do.		
A. Kline	United Comstock mines, Gold Hill, Nev.		

GAS SAMPLING AND ANALYSES

Below is an abstract of a report prepared for the California Industrial Accident Commission by Dr. L. H. Duschak, who spent four weeks at Jackson, Calif., as consulting engineer for the Industrial Accident Commission of California. He desires to acknowledge the assistance rendered by Orr Woodburn, of the Globe-Miami District Mine Rescue and First Aid Association, and of various rescue men working under the direction of the United States Bureau of Mines.

When the fire was discovered in the vicinity of the 3,000-foot level of the Argonaut shaft in California shortly before midnight on August 27, 1922, the mine was being ventilated in the usual manner by an exhaust fan situated near the collar of the Muldoon shaft, which with the communicating system of raises and connections formed the return airway. As no change was made in the system of ventilation after the fire started, a dense cloud of smoke was soon emitted by the fan. This continued for about three hours, after which the density of the smoke cloud materially decreased, but the fan discharge was still of a highly toxic character. Owing to the limitations of the oxygen breathing apparatus, any attempt to reach the working levels of the mine through the Muldoon system was out of the question, as long as the Muldoon atmosphere remained irrespirable. An accurate knowledge of the condition of this atmosphere was therefore essential in planning the rescue program.

Regular gas sampling at the Muldoon fan was commenced on Wednesday morning, August 30. A typical analysis was as follows: O_2, 17.6 per cent; CO_2, 2.8 per cent; CO, 0.7 per cent. Analyses were made with a standard Orsat apparatus, following the procedure outlined by Kreisinger and Ovitz.[1] Carbon monoxide determinations were also made with the carbon monoxide detector,[2] manufactured by the Mine Safety Appliances Co. At this time the churning

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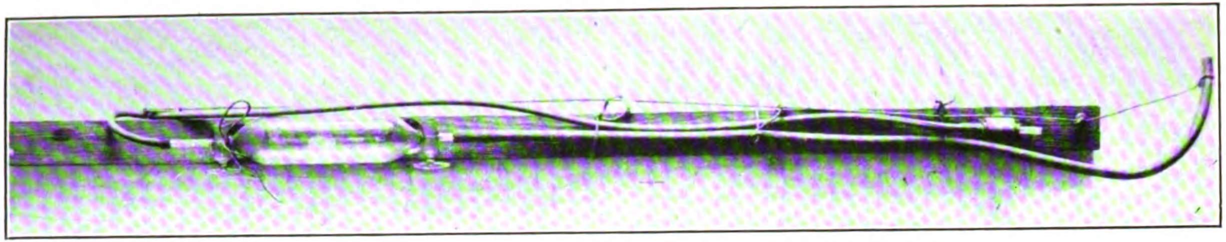
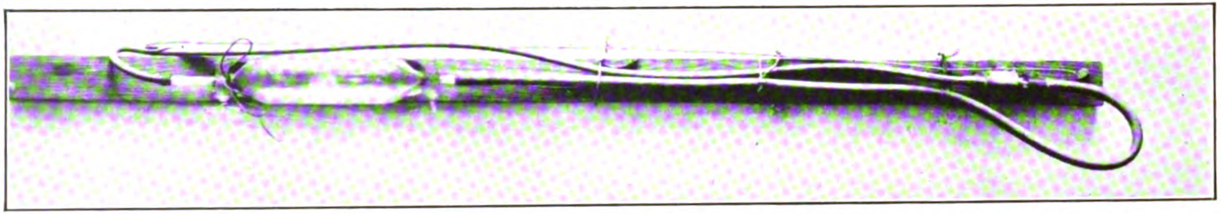
[1] Kreisinger, Henry, and Ovitz, F. K., Sampling and Analysis of Flue Gases: Bull. 97, Bureau of Mines, 1915, 70 pp.

[2] So far as the writer [Doctor Duschak] knows, this was the first time that the carbon monoxide detector has been used to any extent in connection with a mine fire. Its indications were checked repeatedly by the Orsat apparatus, and also confirmed by tests with canary birds. It was found that the color scale in the instrument could be easily read underground in the concentrated beam of two carbide lights or two pocket flash lights. The simplicity of the instrument and the ease with which determinations are made suggest that it might be of use in connection with regular mining operations.



A. GAS-SAMPLING APPARATUS USED BY DOCTOR DUSCHAK—OPEN



B. SAME APPARATUS—CLOSED

of the fan indicated that it was handling much less than the normal volume of air.

During Wednesday and Thursday the composition of the fan discharge remained practically unchanged, indicating that the efforts to extinguish the fire were unavailing. Exploration made Thursday afternoon by an apparatus crew under the direction of the United States Bureau of Mines disclosed burning timbers below the 2,500-foot level. These were extinguished without producing any material change in the gas discharged by the fan and it was evident that a vigorous fire was still burning considerably below this point. On Friday it was decided that further efforts to extinguish the fire by the application of water from above were useless, and a tight bulkhead was constructed across the shaft below the 2,500-foot level. Bulkheads in the drifts on the 2,400-foot and 2,500-foot levels were also repaired and sealed with clay in order to prevent any fresh air from reaching the fire zone. The efficacy of these bulkheads was shown by an almost immediate decrease in the quantity of CO_2 and CO in the fan discharge.

On Sunday, September 3, an exploring party crossed from the Argonaut shaft to the Muldoon end of the 2,400-foot level. The raise coming up to this point carried all of the gas escaping from the lower levels of the mine. A sample taken at that time with the apparatus shown in Plate IV and analyzed later in the usual way had the following composition: O_2, 13 per cent; CO_2, 6.2 per cent; CO, 0.9 per cent. A comparison of this and subsequent samples at this point with samples taken at the fan showed that between the 2,400-foot level and the surface the gas coming from the lower levels of the mine was diluted with approximately twice the volume of fresh air entering through superficial workings.

Systematic sampling was continued both at the fan and the 2,400-foot level, and anemometer and temperature readings were taken regularly at the latter point. Owing to the greater significance of the observations made at the 2,400-foot level a selection from these data, given in Table 1, will be sufficient to show the course of events.

TABLE 1.—*Composition of gases at 2,400-foot level, Argonaut mine*

Date	Time	Temperature	Air volume	Gas composition			
				By Orsat			By detector, CO
				O_2	CO_2	CO	
1922		°*F.*	*Cu. ft. per min.*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Sept. 3	8 p. m.	....	....	13.0	6.2	0.9	....
Sept. 6	11 a. m.	80	5,000	12.8	7.0	.9	....
Sept. 8	4 p. m.	....	4,000	13.6	6.3	.5	....
Sept. 12	3 p. m.	80.6	3,800	15.2	5.0	.6	0.5
Sept. 14	11 a. m.	79.7	3,900	15.5	4.6	.4	.5
Sept. 16	11.15 a. m.	80.0	4,100	15.2	3.9	.2	.1
Sept. 17	3.30 p. m.	80.6	4,500	16.1	4.0	.1	.05

Accurate work with the anemometer was impossible, and the variations in the gas volumes shown above are without significance. The gradual decrease in the CO_2 and CO showed that the fire was being slowly smothered owing to the continued effectiveness of the bulkheads. At times large quantities of water mist were present in the gas coming up the Muldoon raise at the 2,400-foot level. The water mist was doubtless due to one or both of the following causes, namely, the penetration of the fire zone by water or the progress of the fire to a point where considerable water entered the shaft.

The diminution in the carbon monoxide was closely watched from day to day in the hope that the atmosphere in the Muldoon system below the 2,400-foot level would clear sufficiently so that rescue parties could safely descend to the lower levels of the mine through this entrance. The atmosphere, however, remained irrespirable up to the afternoon of September 17, and early in the morning of the 18th connection was made between the 3,600-foot level of the Kennedy and the 4,200-foot level of the Argonaut.

During the time of the exploration work and the removal of the bodies, gas samples were analyzed at frequent intervals, but there was no indication that the air entering the mine through the Kennedy connection caused any change in the fire zone.

CALCULATING THE EXTENT OF THE FIRE

One of the much discussed subjects prior to the entrance of the Argonaut shaft through the Kennedy connection was the extent of the fire zone in the shaft and particularly the question as to whether the 4,200-foot station in the Argonaut shaft would be found intact. On September 4 the writer made a rough calculation of the amount of timber which had been burned up to that time, and at intervals after that this calculation was brought up to date. For the period covered by the gas analyses these calculations were based upon the volume and total carbon content of the gas coming up the Muldoon raise at the 2,400-foot level. For the initial period of the fire assumptions were made as to the volume of air entering the fire zone and the extent to which the oxygen was consumed by the burning timber. According to data furnished by the management, the timber used in the Argonaut shaft corresponded to 1,200 pounds of wood per running foot of shaft. The wood was assumed to contain 50 per cent carbon. A summary of these calculations is given in Table 2.

TABLE 2.—*Estimate of shaft timbering burned*

Date	Time interval	Assumed air volume	Basis of calculation	Wood consumed		Corresponding length of shaft
				Per minute	Total	
	Hours	*Cu. ft. per min.*		*Pounds*	*Tons*	*Feet*
Aug. 28	4	30,000	50 per cent O utilized	200	24	40
Do	20	15,000	do	100	60	100
Aug. 29 Aug. 30 Aug. 31	72	10,000	do	67	144	240
Sept. 1 to Sept. 10.	216	4,000	6.5 per cent $CO+CO_2$	17.6	114	190
Sept. 10 to Sept. 19.	216	4,000	do	12	77.8	130
Total length of shaft timbering entirely consumed						700

The assumptions used in calculating the quantity of timber consumed during the early period of the fire before exact gas data were available were considered to be liberal. The computations based on gas data are fair approximations, but indicate only the quantity of timber totally destroyed. There was no way of knowing whether the timbering in a single continuous section of shaft had been destroyed or whether partial destruction had occurred throughout a greater length of shaft. Balancing these several considerations, the writer expressed the opinion that not more than a thousand feet of shaft timbering had been involved and that consequently the 4,200-foot station would be found intact. Subsequent explorations have shown that the shaft was not burned below the 3,700-foot level, and it seems likely that the estimate will prove to be approximately correct.

VALUE OF GAS ANALYSES

As the events of the Argonaut were followed from day to day one was repeatedly impressed with the fact that the analyses and other observations of the gas stream coming up the return airway furnished the only means of judging what was going on in the fire zone. These observations not only showed that the fire had been placed under control by the bulkheads but also that it was being slowly extinguished. In this case the story told by the gas work is a relatively simple one. During the previous fire at the Argonaut in 1919 a somewhat similar program of gas sampling was carried out and on several occasions variations in the gas composition gave notice of occurrences underground which required immediate attention.

It is possible that the utility of the systematic determination of gas composition, gas volume, etc., in connection with mining operations has not been fully appreciated. Seepages of methane occur in certain formations and there are several cases on record where explosive mixtures of this gas with air have been formed in underground workings in California. Warning of such seepages might be obtained by analysis of the return air before dangerous quantities have collected. In a similar way, the influx of air high in carbon dioxide from old workings, due perhaps to movement of the ground or failure of an old bulkhead, might be detected. The underlying consideration is that an examination of the return air may yield information in regard to an occurrence at a remote point, thus giving notice of a condition which requires attention.

GAS SAMPLING BY BUREAU OF MINES

In addition to the gas work done by Doctor Duschak, several gas samples were taken by the Bureau of Mines and submitted to the Pittsburgh experiment station for analysis. The most interesting of these samples were three which were taken back of the bulkheads and in the region where the dead miners' bodies were found. One of these samples ran as high as 0.21 per cent carbon monoxide and 5.71 per cent carbon dioxide, with the oxygen content 14.18 per cent. The other two samples averaged 0.10 per cent carbon monoxide, 3.25 per cent carbon dioxide, and 17 per cent oxygen. The high carbon monoxide content indicates very definitely that the men died of fire fumes, and that undoubtedly their deaths were not caused by deficiency of oxygen, as the sample showed over 14 per cent oxygen, which would have amply supported life under the existing conditions.

FAILURE TO CONTROL THE FIRE

If a water supply with hose, or even with buckets, had been available on the 3,000-foot station, the discoverer of the fire very probably could have extinguished it.

Positive control of the ventilation could probably have controlled the fire in time to prevent loss of life.

A mine fire-fighting organization, with prearranged plans for such emergencies, would have provided the precautions mentioned.

Bureau of Mines Technical Paper 314, "Metal-Mine Fires" particularly stresses mine fire-fighting organizations and prearranged plans. The bureau has repeatedly emphasized these factors because it believes that preparedness through anticipation will be of the utmost value in saving lives. Definite plans of action, trained crews, instructions to underground men on barricading, fire drills, ventilation control, and other precautions are fully discussed in Technical Paper 314. They should interest all responsible employees of metal-mining companies.

EFFECTS OF THE FIRE

In addition to the loss of the 47 miners, the Argonaut shaft was burned for a distance of about 800 feet (12 sets below the 2,550 station to a few sets below the 3,450 station), and operations in the Argonaut mine were suspended for about nine months. Besides the shaft timbers the fire also burned two ventilation units (a bulkhead on the 2,750-foot level 50 feet from the station and a door on the 3,300-foot level 60 feet from the station), two sets of timber in a drift at the shaft station in the 3,300-foot level, and 1½ boxes of powder stored on the 3,300-foot level by the ventilation door mentioned. With the exception of the timber on the 3,300 level no timber was left between the stations and doors. In the fire area the timber was entirely burned. At a point approximately 60 feet below the 3,150 station the first débris was found in the shaft; it consisted of rails, pipes, and the remains of the power cable which had broken loose above the 2,750 station. The rails and pipes were badly twisted and bent, showing that they had been subjected to considerable strain.

COSTS OF THE FIRE

No definite figures on the cost of the fire are available. The main cost to the company included compensation to the families of dead miners, the delay entailed in production, the cost of fire fighting and mine rescue work, the cost of driving the 3,600 and 3,900 connections in the Kennedy mine, and the cost of recovering the Argonaut mine.

The Kennedy mine was put to considerable expense by having to suspend operations for about four weeks. The demoralization of miners in all the California gold-mining districts is also to be considered in the total cost.

The lessons learned from the fire, however, may be the means of preventing similar fire catastrophies, because almost immediately the mine managers throughout the metal-mining districts of the country began to consider the possibility of a similar disaster in their mines and to plan many preventive measures. The California Industrial Accident Commission, with the cooperation of California mine operators, prepared special mine fire-control safety orders (printed on p. 34), and recently made them effective, in the hope that similar disasters would thereby be prevented.

LESSONS FROM THE FIRE

Investigations and studies of mine fires bring out many lessons that should be valuable to operators and miners at times of emergency or in preventing catastrophies. Many of the lessons are not new but are important enough to merit further study by those working in mines. Most fires and the results of fires are chargeable to carelessness and neglect.

As the author desired to cover the subject as extensively as possible, he requested and received individual opinions from all the Bureau of Mines representatives at the fire, and in addition from Director H. Foster Bain and Chief Mining Engineer George S. Rice, of the Bureau of Mines. The following lessons are abstracted from their suggestions, with additions by the author.

NEED FOR PREVENTIVE MEASURES

1. No feasible State regulation can cover all conditions of hazard at every mine. Some hazards can not be eliminated except at prohibitive cost. No cost, however, which will still permit the financing and operating of necessary mines is too great if it affords real protection to life and property. Mine operators and miners must both recognize the risk, and more time and more thought must be given to applying to individual mines the safety recommendations of State officials and of the Bureau of Mines.

2. In spite of the fact that metal operators, in general, believe that metal mines can not have disastrous fires, the Argonaut fire and the North Butte disaster show that fires can occur in metal mines and can cause heavy loss of life if no precautions or preventive measures have been taken.

CONTROL OF VENTILATION

3. Too little attention is paid to the importance of controlled ventilation. Every mine should be provided with fan ventilation, so placed that by manipulation of a few doors the ordinary direction of air currents could be quickly reversed. This fan should be preferably on the surface, should have fireproof housing, should be operated throughout the entire 24 hours, and should not be stopped or reversed except by the direction of the mine superintendent or mine manager or, in his absence, only after careful consideration by the persons in charge.

4. All underground openings, including shafts and inclines as well as tunnels which act, or may act, as air courses, should be guarded by doors in such manner that, if desired, an air course may be completely isolated by closing these doors. Such doors should be solid, and practically fireproof, and should be equipped with a positive latch, so that even in case of reversal of direction or pressure of air they will remain closed. The latch should be arranged so that it can be easily operated from either side of the door.

5. A fire in a deep mine will prove disastrous to men underground if their escape ways are cut off, unless every possible precaution is taken to short-circuit the resultant fire gases.

FIREPROOFING

6. All timbered shafts should be fireproofed or fire-protected. Where this is not feasible, the timbered stations should be positively fireproofed. Particularly should the space around electric devices and switches be fireproofed.

7. Mine fires can be prevented only if they are anticipated and proper fireproofing is done at critical or key points.

TRAINING AND ORGANIZATION

8. Every mine should have perfected an organization for the prevention and control of mine fires. Such organization should include not only the various mine officials but every workman as well.

9. All bosses should be instructed to take care of their men and to notify and direct them in case of anticipated danger.

10. All underground employees should be instructed and thoroughly trained in what to do in time of disaster.

11. An executive committee, in complete charge of all operations, delegating its powers to individuals, should be in control of every large catastrophe.

12. Where oxygen breathing apparatus is being used, the crew should be thoroughly organized and captains selected with great

care. The personnel of each crew should not be changed, but it is well, however, to have well-trained substitutes for use in an emergency.

The group-and-shift organization of apparatus men at the Argonaut proved very successful, and is recommended when enough apparatus men are available.

Where possible, apparatus men should be supported by fresh-air men.

13. Each mining company should have at least 10 regularly trained apparatus men for every 100 men employed.

14. Men trapped in a burning mine will generally find a natural leader, who will sensibly direct them.

EQUIPMENT

15. Fire-fighting equipment, discussed in Bureau of Mines Technical Paper 314, should be available for instant use as soon as the fire is reached, for in a main airway fire gains such a rapid headway that it soon gets beyond control.

16. In fighting any underground fire by positive methods, an unlimited water supply, with standardized hose and hose connections, should be immediately available.

17. Every operating mine should have an auxiliary or emergency set of signal devices. If possible, the telephone circuit should be arranged to pass into the mine through each exit.

18. Oxygen breathing apparatus is invaluable in fighting a mine fire, in exploring the mine, in restoring ventilation, and in recovering dead bodies. Without it at the Argonaut, little could have been done to recover the mine.

19. Each mining company should have available at least six sets of oxygen breathing apparatus with plenty of spare parts, oxygen pump and tanks, and regenerating material, and should be a member of a central or district fire-fighting station.

20. Airplanes, when available, are valuable to transport men and supplies quickly at time of mine fire.

PRESENCE AND EFFECTS OF CARBON MONOXIDE

21. A man working for some time in a fire atmosphere that does not affect a candle flame and may not overcome a canary bird can accumulate in his blood enough carbon monoxide, if it is present even in minute quantities, to make him violently ill. Many men working in the Argonaut shaft and later in the 4,350 level, where neither canary bird nor candle were affected, developed severe headaches and vomited. Such atmospheres undoubtedly contained small percentages of carbon monoxide.

22. As high as 0.21 per cent of carbon monoxide was found behind the miners' bulkheads, which had been built three weeks before they were opened.

BULKHEADS

23. If bulkheads are used to control a shaft fire they can be quickly and cheaply constructed of two layers of 2 by 12 boards laid criss-cross, covered with tar paper, and with the cracks and openings sealed with wet clay. Such bulkheads, to be effective, must be kept wet. Water collecting on the top of a bulkhead is dangerous, and a pipe in the shape of a gooseneck can be inserted for drainage. Such a gooseneck will hold enough water to prevent the leakage of air.

24. All bulkheads built to control mine fires should be patrolled at regular intervals. If a cement gun is available it should be used to make the stoppings impervious, lasting, and fireproof by a thick layer of reinforced gunite.

FIRES IN INCLINED SHAFTS

25. An inclined-shaft fire can sometimes be successfully fought and controlled with its own gases, where ventilation is mechanically controlled.

26. Shaft timbers burning in inclined shafts fall and quickly spread the fire. The fire in a downcast inclined shaft will burn up the shaft against the air sometimes as rapidly as it spreads by the falling of burning timbers below the fire.

27. Where there are rails, cables, and pipes in an inclined shaft, in all probability a fire will bulkhead itself off eventually at some point below. Falls of roof are sure to occur and the ore pockets will be drained of ore; this falling material lodges and forms an effective bulkhead.

TECHNICAL AIDS TO VALUABLE INFORMATION

28. Gas analyses by trained chemists, using Orsat apparatus and the newly invented carbon monoxide detector, give extremely valuable information on underground conditions during a mine fire and make intelligent planning possible.

29. Temperature readings and air-velocity and pressure readings are also invaluable aids.

30. The geophone can sometimes be used advantageously at times of mine fires to listen for signals from entombed men.

IDENTIFICATION METHOD

31. Some of the bodies were identified with much difficulty, partly because some of the miners neglected to take their number tags

underground. If a number system is used at any mine, it should be rigidly enforced.

INFORMATION TO PRESS

32. Where the work on a disaster is long drawn out, special arrangements should be made to properly inform the press and moving picture representatives.

CALIFORNIA MINE FIRE-CONTROL SAFETY ORDERS

The Industrial Accident Commission of California called a conference of mine operators, mine employees, and others interested in fire prevention in mines, which met at the commission's offices in San Francisco on October 24 and November 6, 1922. As a result of this conference a committee consisting of mine operators, mine employees, and mining engineers representing the industry at large and the Industrial Accident Commission were appointed to serve on a committee to offer suggestions to the commission regarding mine fire control.

The personnel of this committee was as follows:

Representing mine operators

W. J. Loring (chairman), A. P. Busey, Jr., F. W. Nobs, and O. McCraney.

Representing labor

James Lord, R. W. Rodda, J. C. Williams, and Robert Milligan.

Representing California Metal and Mineral Producers Association and American Mining Congress

Edwin Higgins.

Consultants representing the industry at large

U. S. Bureau of Mines—Geo. S. Rice, Byron O. Pickard, Geo. J. Young, and R. E. Tremoureux.

Representing Industrial Accident Commission

G. Chester Brown (secretary), F. L. Lowell, and H. M. Wolflin.

The Industrial Accident Commission, upon receipt of the committee's report, prepared tentative mine fire-control safety orders, submitted them to employers and employees, and called a public hearing to consider them. This hearing was held on December 7 and 8, 1922, at the offices of the commission in San Francisco. As a result of the hearing the commission appointed another committee to compile mine fire-control safety orders, after giving consideration to the views expressed at the hearing.

The personnel of this committee was as follows:

B. O. Pickard (chairman), district mining engineer, Bureau of Mines, Berkeley; G. Chester Brown (secretary), chief mining engineer, Industrial Accident Commission; W. J. **Loring**, general manager Plymouth Consolidated Gold Mines, Ltd., and president Carson Hill Consolidated Gold Mines, Crocker Building, San Francisco; **Arthur B. Foote**, manager The North Star Mines, Grass Valley; **James Lord**, American Federation of Labor, San Francisco; **Geo. J. Young**, western editor Engineering and Mining Journal-Press, Rialto Building, San Francisco; R. W. **Rodda**, president Empire chapter No. 6, Joseph A. Holmes Safety Association, Grass Valley.

W. E. **Colby**, attorney, California Metal and Mineral Producers Association, San Francisco.

Warren H. Pillsbury, compensation attorney, Industrial Accident Commission.

H. M. **Wolflin**, superintendent of safety, Industrial Accident Commission.

F. L. **Lowell**, mining engineer, Industrial Accident Commission.

The above committee unanimously agreed upon the mine fire-control safety orders and these orders were then adopted by the commission, to become effective on March 15, 1923.

ENFORCEMENT OF ORDERS

Order 1777.

Certain fundamental rules applicable to the majority of mining properties should be adopted for the protection of workmen. In drafting the following mine fire-control safety orders it has been borne in mind, however, that mine fire protection depends to a large extent on local conditions and that conditions vary greatly in different mines and in different parts of the same mine. Where the enforcement of any order would work a hardship or fail to provide adequate protection in any individual mine, or where any order is unnecessary because of absence of fire hazard:

(*a*) Such individual mine, if it desires exemption, must apply for, and the Industrial Accident Commission may grant an exemption from or authorize a substitute for, any order not reasonably applicable.

(*b*) The Industrial Accident Commission may, by special hearing and special safety order, as provided by the Workmen's Compensation, Insurance, and Safety Act of 1917, prescribe a special plan for fire prevention and fire control in a particular mine, as a substitute for the requirements made by these orders, where they do not reasonably apply, provided that the measure of safety prescribed by such special safety order shall be substantially equivalent to the measure of safety contemplated by these orders.

Order 1778.

The superintendent of each mine shall, within 30 days from the date these orders become effective, formulate and report to the Industrial Accident Commission his plans for compliance with these orders, stating, in addition, when work on such plans will be commenced and when such work will be completed. Such work shall be commenced within 30 days from the date these orders become effective and shall be completed within six months thereafter, unless the time be extended by the Industrial Accident Commission.

ORGANIZATION

Order 1779.

(*a*) The superintendent of each mine shall organize his employees for fire prevention, fire control, and the rescue of men underground, and shall formulate and reduce to writing a plan of action to be followed in case of fire in designated zones of the mine. He shall instruct his underground technical staff, foremen, bosses, hoist engineers, skip tenders, shaft topmen, and other employees whose services will be required in emergencies in the duties assigned to them, and shall require such men to attend monthly classes of instruction.

(*b*) To insure the familiarity of all employees with the rules and appliances provided for fire emergencies and with the emergency exits, general fire drills shall be held at least once in every three months for each shift. At these drills the men need not be removed from the mine, but shall be assembled in the main exits or in the stations.

Order 1780.

(*a*) Within 90 days after the adoption of these orders each mine shall prepare a diagram showing the position of (1) exits, (2) principal levels, (3) manways, (4) tunnels, (5) shafts, (6) fire doors, (7) water lines available for fire fighting and fire extinguishers, (8) telephones and telephone lines, (9) principal compressed-air lines, (10) direction of air currents, and (11) refuge places. Such diagram need not show boundary lines, outlines of ore bodies, or other details not essential for the safety of the employees. Copies of said diagrams shall be placed in frames behind glass near the entrance of the mine most frequently used by the men and at such principal working stations as may be designated by the superintendent. A copy shall be sent to the department of safety of the Industrial Accident Commission. This diagram shall be brought to date at least once in six months.

(*b*) The superintendent shall require weekly inspection of the main shaft and the underground workings for any conditions tending to increase the fire hazard. Second exits and other portions of the mine not regularly frequented shall be inspected for fire hazards and deterioration of ladders or of other appliances necessary to maintain an adequate escape way, upon regular rounds through such places, and in any event at least one each month. If any condition be found in a second exit making it inadequate for an escape way, repairs shall be commenced immediately and completed with reasonable diligence. A signed report of each inspection shall be kept in the mine office, whether hazardous conditions be found or not. (NOTE.—See Mine Safety Order 1701 (*b*) for requirement of special reports to be made to the Industrial Accident Commission regarding any unusual hazard noted.)

FIRE-FIGHTING EQUIPMENT

Order 1781.

Each mine in which the main working shaft or adit is timbered and the timber is not protected against fire by fireproofing or by being constantly wet, or in which mine stations are in an inflammable condition, or wherein the workings are considered by the Industrial Accident Commission to constitute a local fire hazard of more than nominal proportions, shall be equipped with the following fire-fighting apparatus, which shall be maintained in good order, available for instant use:

(*a*) A supply of water for fire fighting so distributed that a stream of water can be had at any mine station at which a fire hazard exists and throughout timbered and nonfireproofed portions of the shaft, with necessary connections for the attachment of hose[3] and the adequate supply of hose so arranged that it can readily be put in a skip, cage, or other conveyance. The hose shall be kept at the mine entrance and on each working level and at such other places as may be required by the Industrial Accident Commission. All water-main outlets, hose couplings and nozzles shall be of standardized size throughout the mine.

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[3] Attention is called to the advisability of having connections for hose so placed that a stream can be directed upon any station from above and below the station in the event of a fire at the station.

(*b*) Where the water supply is inadequate or can not practicably be applied to meet the requirements of subsection (*a*) above, special fire-fighting equipment and protection according to a plan to be submitted to and approved by the Industrial Accident Commission.

(Attention is called to the possibility of using water skips or connections so arranged as to direct a stream of water around the entire area of the shaft. Chemical fire extinguishers of approved types would also be applicable under this section.)

(*c*) All electrical equipment underground, such as motors, transformers, etc., shall be provided with a supply of dry sand, supplemented by one or more small fire extinguishers of a type approved by the Industrial Accident Commission. Where carbon tetrachloride extinguishers are provided, care must be taken that they be not used where the ventilation is deficient.

(*d*) In addition to requirements of Mine Safety Order 1725, there shall be provided at all mine openings where inflammable structures exist a system of fire hydrants with sufficient hose or monitors properly placed and connected with the main water-supply system.

(*e*) All equipment intended solely for fire-fighting purposes shall be tested or carefully inspected at monthly intervals and defective equipment replaced immediately. All hand chemical fire extinguishers of the soda-acid type shall be refilled every six months and the date of last refilling marked on a tag attached to the extinguisher.

CONTROL OF VENTILATION

Order 1782.

(*a*) Emergency fire doors or bulkheads shall be placed throughout each mine to prevent smoke and gases from any fire cutting off the escape of men working in the mine, according to a plan to be submitted to and approved by the Industrial Accident Commission. Such doors may also be used for the control of normal mine ventilation.

(*b*) The bulkheads, door frames, and fire doors shall be constructed of gas-tight material.

(*c*) The fire doors shall be provided with suitable latches or other mechanical device, so that they may be opened from either side, but can not be opened by the reversal of the air current.

Order 1783.

(*a*) Mechanically produced and positively controlled air currents shall be provided for each mine more than 1,000 feet in depth (measured along the line of the shaft), unless it be proved to the satisfaction of the Industrial Accident Commission, as evidenced by its written approval, that mechanically produced air currents would not be feasible, effective, or necessary.

(*b*) When fans are used, the principal fan or fans shall be installed on the surface, and air ducts so arranged that mine entrances can be used for rescue or other purposes. Such fan or fans shall be so installed that the ventilating current can be quickly reversed in direction. All surface fans, casings, and air ducts connecting with the mine openings, and also the fan houses and other buildings in close proximity, shall be made of noncombustible material throughout, or, if of combustible material, shall be fireproofed. All underground fans operated by electric motors shall be of noncombustible construction and the immediate vicinity fireproofed if combustible material be present. No surface fan house shall hereafter be erected within 50 feet of any inflammable structure.

EMERGENCY EQUIPMENT

Order 1784.

(*a*) At every mine employing more than 25 men underground on any one shift, there shall be provided five sets of approved oxygen breathing apparatus, which shall be maintained in good order in a readily accessible fireproof place on the surface. Every mine employing 25 men or less underground on any one shift, but having 10 or more employees in all, shall, within 30 days from the date these orders become effective, submit to the Industrial Accident Commission a description of its fire hazard with reference to the lives and safety of its men, and its plans, if any, for providing oxygen breathing apparatus and men trained in its use and in rescue work. If it should appear to the Industrial Accident Commission that such mine is not or can not practically become a member of a cooperative mine rescue station because of isolated location or otherwise, and that oxygen breathing apparatus should reasonably be provided, the Industrial Accident Commission may order the installation of such oxygen breathing and other rescue equipment as may be advisable under the circumstances.

(*b*) Any mine that is a member of a cooperative mine rescue station equipped with ten or more sets of oxygen breathing apparatus that can be brought to the mine in good order within one hour after notification need not provide oxygen breathing apparatus for its individual use. At the cooperative stations sufficient spare parts shall be kept to assemble at least one additional apparatus in good working order in addition to the parts and supplies required by Mine Safety Order 1704 (*d*).

Each cooperative station shall have a foreman in charge; he shall occupy living quarters adjacent to the cooperative station and shall be available immediately to all members of the station in time of emergency. Telephone communication shall be maintained between the cooperative station, the foreman's residence, and each mine served by such station.

(*c*) Each mine employing more than 25 men underground on any one shift shall have approximately 5 per cent of its underground force on any one shift, with a minimum of 5 men, trained in the use of oxygen breathing apparatus. Such men must renew their training at intervals of at least once in each two months by wearing apparatus in noxious atmospheres for one hour.

The foregoing requirements covering the maintenance of oxygen breathing apparatus are in addition to paragraphs (*e*), (*f*), and (*h*) of Mine Safety Order 1704.

Order 1785.

(*a*) Each mine required to have a second exit shall maintain two telephone lines so arranged as to provide two means of communication between each working level and the surface. Such lines shall be placed in separate shafts or openings. Such telephone lines must be tested weekly and maintained in workable condition.

(*b*) Each mine required to have a second exit, except such as are excluded hereafter, shall maintain in it an auxiliary compressed-air line with proper outlets at suitable points for use in emergency at working levels and elsewhere, in addition to the line provided in the main working shaft. Such second compressed-air line shall be at least 2 inches in diameter (except where a smaller size is approved by the Industrial Accident Commission), and be connected with any underground refuge chambers. This requirement does not apply to mines connected with adjoining mines at or near working levels or to any mine where it is established to the satisfaction of the Industrial Accident Commission, as evidenced by its written approval, that an adequate supply of good air can be supplied to workmen below, in the event of a fire, by mechanically-controlled ventilation or otherwise.

Order 1786.

Where connections have been established between adjoining mines for an emergency exit, two doors shall be provided in the connecting passage, and each mine shall provide a telephone between the doors. Compressed-air lines equipped with valves shall be run from the compressed-air system of each mine to the space between the doors, but need not be interconnected. (For additional requirements, see Mine Safety Order 1723.)

Order 1787.

Each mine required to have a second exit, except as exempted below, shall be provided with one or more places of refuge, suitably placed, protected from gas or fire by adequate fire doors, and provided with telephones and compressed-air lines, connected with both the main and auxiliary telephones and air lines. Such places shall contain materials ready for use to make the fire doors air-tight, such as cement, clay, or oakum. Such places shall be further provided with water sufficient for refuge purposes. Such water must be changed at reasonable intervals. The provisions of this section shall not apply where the second exit is in such condition that it will require one hour or less for employees to come from the bottom level of the mine to the surface through it, or where a connection is made with an adjacent mine, or where sufficient good air can be supplied to workmen below, in the event of fire, by mechanically-controlled ventilation or otherwise.

Order 1788.

Each mine required by law to maintain a second exit shall protect underground employees against the hazard of all exits becoming impassable through fire or fire gases, by one or more of the following methods:

(*a*) By fireproofing the main shaft and shaft stations, provided that where there is no fire hazard sufficient to interrupt the use of the main-shaft hoist for rescue purposes such conditions shall be a sufficient compliance.

(*b*) By maintaining a connection between working levels of such mine and an adjoining operating mine.

(*c*) By such mechanical control of the air currents as will permit the supplying of good air through any shaft or escape way by reversal of air currents if necessary.

(*d*) If none of the foregoing methods can be made applicable to a particular mine, such mine may, after a special hearing, be required by the Industrial Accident Commission to install and keep in usable condition a hoist in a second exit.

(Where the use of a series of raises is contemplated for an emergency exit, the mine management is strongly advised to select the position of the raises so as to have them in line with one another, so that hoisting equipment can be installed if advisable at some future time.)

Order 1789.

A surface fire alarm, consisting of a siren or equivalent device, shall be installed and used for the purpose of giving a general fire alarm at the surface when fires are reported in the surface plant or underground. As a means of informing underground workers of fire, mines that are equipped with a compressed-air system shall install an approved method of stench warning, and in addition shall establish a general danger signal by flashes or distinct interruptions of the electrical lighting current or by telephones.

FIRE PREVENTION

Order 1790.

(*a*) All material near the electrical equipment, such as motors, transformers, etc., shall be noninflammable or fire resistant.

(*b*) All used mine openings for a distance of 25 feet from the surface and all used underground stations having a fire hazard shall be constructed of fireproof material or maintained in a noninflammable condition by the use of water. Steel supports, concrete, gunite, or cement plaster are recommended for consideration. It is further recommended that at regular intervals in the main shafts and haulageways certain sections be made fireproof. (NOTE.—See Mine Safety Order 1741 (*g*), Inflammable Structures Near Mine Opening.)

Order 1791.

Fires for heating shall not be permitted underground, and open torches, acetylene lamps, and candles shall not be left unattended in any mine in the vicinity of wood or other inflammable material. (This shall not be construed to prohibit the use of torches or heating devices necessary for mechanical repairs, provided such devices have continual attendance while lighted.)

Order 1792.

The electrical safety orders issued by the Industrial Accident Commission apply to mining operations. All electrical equipment shall be carefully inspected monthly by a competent person designated by the mine superintendent.

REPORTS

Order 1793.

The superintendent of each mine shall file with the Industrial Accident Commission such additional reports, plans, diagrams, and maps relative to fire protection and prevention as may be required by the commission. The Industrial Accident Commission will furnish forms for all required reports.

BUREAU OF MINES PUBLICATIONS RECOMMENDED

Many further details and specific recommendations regarding mine fires will be found in the following Bureau of Mines publications:

Bulletin 188, "Lessons from the Granite Mountain shaft fire, Butte."
Technical Paper 24, "Mine fires, a preliminary study."
Technical Paper 251, "Ventilation in metal mines."
Technical Paper 314, "Metal-mine fires."
Miners' Circular 25, "Erection of barricades during mine fires or after explosions."

Technical Paper 314, which gives special recommendations on the prevention of metal-mine fires, should be read in connection with this paper.

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